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# **A New Nonmonetary Metric for Indicating Environmental Benefits from Ecosystem Restoration Projects of the U.S. Army Corps of Engineers**

Report 2

Richard A. Cole

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Report 2 of a series

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**Abstract:** A new environmental benefit metric is described and proposed for use in planning environmental quality improvement projects using an ecosystem restoration approach. Called the Biodiversity Security Index (BSI), the metric indicates the value gained from securing the Nation's native species from decline toward extinction by providing more natural ecosystem support. The BSI takes different forms of expression depending on ecosystem restoration project reconnaissance, feasibility study, and program budget planning needs. In its simplest form, the index score is the sum of indicator species identified to be insecure in the ecosystem planned for restoration. The most advanced form requires estimates of the number of viable population units restored and includes indicators of species distinctiveness, based on taxonomic differences, and unmanaged risk of species recovery failure. Policy-determined weights are applied to reflect the relative importance placed on species security, species distinctiveness, and risk of viable population units not being recovered as planned. The metric appears to be consistent with Federal project planning and feasibility study objectives described in Corps planning policy. Its direct indication of benefits and comparability across projects are major advantages over other metrics now in use.

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## Preface

This report is the second in a series of three reports on environmental benefits measurement for Army Corps of Engineers projects planned and designed for restoring environmental quality using an ecosystem restoration approach. The author of the report, Dr. Richard A. Cole, is an Environmental Planner at the Institute for Water resources, U.S. Army Corps of Engineers (Robert Pietrowsky, Director). For their review comments and related discussions, the author is indebted to Ellen Cummings from Corps Headquarters; to Lillian Almodovar, Keith Hofseth, Michael Lee, and Dr. Norman Starler from the Institute for Water Resources; and to Drs. Andrew Casper and Barry Payne at the U.S. Army Engineer Research and Development Center. Glenn Rhett (Program Manager) and Dr. Al Cofrancesco (Technical Director) facilitated the review process at ERDC. The author also benefited from discussions with many others, but especially Paul Scodari, Lynn Martin, Leigh Skaggs, and Bruce Carlson.

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COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

# 1 Introduction

This technical report describes a new nonmonetary metric concept, the Biodiversity Security Index (BSI), which can be used to indicate benefits that cannot be acceptably measured in monetary units or evaluated using economic benefit-cost analysis. The BSI was developed to address the planning needs of the U.S. Army Corps of Engineers (USACE), but may have applications elsewhere. This paper is second in a series of three. Background for the BSI development can be found in a review of practices used to establish and measure environmental value in and outside of the Federal government (Cole, in preparation (a)), including the Corps. A third report (Cole, in preparation (b)) compares the BSI concept with the concepts of other metrics used by the Corps for their consistency with scientific principles, Civil Works planning policy, and Corps restoration practices.

Development of the BSI rested on the underlying assumption that an acceptable metric should be consistent with agency authority and achievement of program objectives. The metric proposed here is based on the objectives for Federal water resources planning identified in the Water Resources Planning Act of 1965, the Corps environmental quality restoration authority established in 1996, and the interpretation of those authorities in planning policy guidance (USACE 2000). The general intent of Federal water resources project and program planning is to return the greatest benefit to the Nation for the Federal investment in projects and programs.

Policy guidance requires justification of investments in water resources project planning (feasibility study) and plan implementation (construction) based on the benefits they produce. It directs the estimation of project plan costs and benefits in monetary terms when acceptable and the use of cost-benefit analysis to evaluate and compare plans for selection and implementation recommendations. This is to be done for all authorized Civil Works purposes pertaining to improvement of water resource use (e.g., navigational, floodplain, and recreational use) and for incidental uses that are not authorized among Corps purposes. Environmental quality (EQ) protection is incorporated into the costs and the benefit-cost analysis. Use value in general is measurable in monetary

terms using widely used techniques (National Research Council (NRC) 2005). All but one authorized purpose of the Corps pertains to improved value in the use of water resources.

The exception, the environmental quality (EQ) improvement authority, requires an ecosystem restoration approach. Restoration project investments are to be reserved for benefits that cannot be measured acceptably in monetary terms, according to Corps planning policy guidance. In addition to use value, utility value that can be considered in the planning process includes nonuse value, also known as existence value (Krutilla 1967, Freeman 2003, and NRC 2005). Nonuse value is associated with restoring and protecting desired resources from any destructive use that compromises future use options and opportunities. Based on theoretical and practical questions about existing techniques (NRC 2005), Corps policy (Cole, in preparation (a)) does not accept measurement of nonuse value in monetary terms (see Cole, in preparation (a) for more detail). By deduction, the target of ecosystem restoration is improved nonuse value.

Revision of the planning policy guidance (USACE 2000) established a new Federal project planning objective statement for the Corps consistent with its new EQ restoration authority. In effect, it created two sub-objectives within the Federal project planning objective. Plans should be recommended based on beneficial contributions to the achievement of national economic development (NED) and/or national ecosystem restoration (NER) sub-objectives. When projects include both NED and NER planning objectives, the optimal plan that produces the most benefit ordinarily is to be selected. In those project settings, the benefits produced include use value associated with NED, which can be measured acceptably in monetary terms, and nonuse value associated with NER, which, consistent with Corps policy, is measured in nonmonetary terms. All significant benefits and costs associated with resource use and nonuse are to be accounted for and considered in the planning process. The plans for a single-purpose ecosystem restoration project are evaluated based on their nonuse benefits but, consistent with policy guidance, incidental NED benefits are measured in monetary terms and considered when the best plans have similar nonuse benefits. Corps policy requires that all nonmonetary benefits be quantified to facilitate comparisons with each other and monetary benefits.

Not finding any single metric suitable for measuring the benefit from EQ restoration, policy guidance allows any nonmonetary metric to be used that can be clearly related to the project planning objectives. A wide variety of different metrics have been used. In addition to project planning, the Government Performance and Results Act requires projects to be ranked based on the value they add to the Nation to facilitate annual allocation of budget to project planning and implementation. A recent description of the metrics is found in USACE (2009). Because no single metric had been developed for project planning, a new metric was developed for ranking projects according to the value they added. But it is not suitable for project planning. Unclear relationships among the many different benefits metrics and planning objectives contribute to the strain on planning communication and quality control. The BSI was developed in response to desired improvement.

## 2 Methods

The BSI concept grew out of an investigation of environmental benefits analysis for ecosystem restoration in the Corps (Stakhiv et al. 2003). One of its recommendations was to consider a metric based on the scarcity of biodiversity to improve measurement of environmental value added by ecosystem restoration projects. Development of the metric concept relied on a review of practices used outside the Corps to measure environmental value (Cole, in preparation (a)). That review established a list of variables that are commonly used to indicate value consistent with the ecosystem restoration planning needs of the Corps. The three most commonly encountered variables indicating benefits included resource scarcity, distinctiveness, and threats or risks facing the protection or restoration of desired resources. Variables were sometimes included that contributed to risk management, such as restoring ecological keystone and dominant species, or flagship (charismatic) and economically important species that would attract project funding.

BSI development also responded to the qualities of the resource outputs desired from Corps ecosystem restoration projects as indicated in the authority, purpose and ecosystem restoration study objectives of the EQ restoration program. The essential aspects are summarized here starting with the authority. The programmatic EQ restoration and protection authority is found in Section 206 of the Water Resources Development Act of 1996. Identification of the desired outputs requires more specific definition of EQ, which is elaborated in Corps policy guidance. EQ was first established as a protection and improvement objective separate from economic development objectives and guidance (Water Resources Council (WRC 1973) determined that EQ improvement is not economic development (WRC 1973). EQ is defined in Federal project planning guidance (WRC 1983) in terms of cultural (including historic) and natural resources with ecological, cultural, and aesthetic attributes. But the ecosystem restoration purpose defined by USACE (1999) limits EQ improvement using an ecosystem restoration approach to restoring “significant ecosystem structure, function and dynamic process that have been degraded.” Thus the desired outputs are limited to ecological resources important enough to warrant the cost of reducing their degradation. To assure that only ecological resources were included among

the desired outputs, the ecosystem restoration policy explicitly excludes cultural, historic, and aesthetic resources from consideration.

With a few modifications, the statement of ecosystem restoration purpose in USACE (1999) became the basis for the feasibility study objective of restoration planning stated in new planning policy guidance published a year later (USACE 2000; Cole, in preparation (a)). Consistent with the ecosystem restoration approach required in the EQ improvement authority, the study objective added a constraint—that the degraded ecological resources are restored “to a less degraded, more natural condition.” But the objective statement also lists the only indicators of EQ restoration success provided in policy guidance. Based on those indicators, the desired outputs include the “ability of the area to sustain...more biologically desirable species,” “a large variety of native plant and animals,” and the “ability of the restored area to function and produce the desired outputs” (USACE 2000; Cole, in preparation (a)). Thus ecosystem support is desired indirectly to recover and sustain the desired outputs, which in the examples provided appear to be the diversity of native species desired for their distinctive biological attributes. The policy guidance provides no other examples (other than indicator species that indirectly indicate the desired outputs), but does not exclude the possibility that others exist. No others were discovered during this review.

Planning policy guidance makes one other important point—that “documentation on the relative scarcity of the resources helps determine the significance of the resources to be restored.” The scarcity of resource supply with respect to what is desired (demanded) is the basic determinant of resource value. Thus the scarcity of biological attributes contributing to native plant and animal diversity is an indicator of whether an objective achieves success, the value added by a project, and the benefits used to evaluate the project. The new metric presented here, the BSI, indicates the benefit of restoration projects based on the scarcity with respect to desired condition and the unique attributes of all plant and animal species in the ecosystem planned for restoration in the project area.

Evidence that the public desires to restore species based solely on the scarcity of their biological attributes is clear in the provisions of the Endangered Species Act. Listing of threatened and endangered species for protection is determined based on their unique biological attributes and their expertly assessed scarcity. The ESA is intended to encourage and

establish conservation programs meeting standards that are, as stated in the law, a “key to meeting the Nation’s international commitments and to better safeguarding, for the benefit of all citizens, the Nation’s heritage in fish and wildlife.” This biological heritage is an important part of the Nation’s natural heritage, the preservation of which is identified among the goals of the National Environmental Policy Act (NEPA).

Planning policy guidance indicates that EQ protection and, by deduction, EQ restoration and protection by the Corps, pertain to heritage maintenance. To the extent it is desired by the public, natural ecological heritage has nonuse value. The expression of nonuse value that is most clearly indicated in the planning policy guidance examples of success is biological heritage. Maintenance of natural biological heritage is consistent with principles of sustainable development (World Commission on Environment and Development (WCED) 1987; The President’s Council on Sustainable Development (TPCSD) 1996) and a goal of environmental sustainability accepted by numerous agencies, including the Corps (USACE 2002). While environmental sustainability may benefit present resource users, the concept is clearly anchored in commitment to sustain opportunities for future generations through the cultural and natural heritage left to them.

The BSI concept was developed incrementally, producing several different general forms, each useful for different project planning and program purposes. These range from project reconnaissance studies to the more complex evaluation of project implementation plans and project ranking for the annual construction budget.

### 3 Results

#### Metric concept overview

The BSI measures contributions to sustaining the Nation's native biodiversity and its natural biological heritage based on the scarcity and distinctiveness of species attributes, the number of species populations with potential for restoration, and the risks of population restoration failure in the project area. The heritage, species, scarcity and distinctiveness orientation of the BSI responds to policy indicators of the desired outputs, which are species, diversity, and scarcity oriented. A more fundamental assumption of the metric is based on the environmental sustainability and natural heritage goals established in government agencies, including the Corps. Its concept creation assumes that the decline of species into global extinction at rates faster than natural rates of species extinction and origin diminishes ecosystem and environmental sustainability, and the natural heritage left to the future. It also assumes that species sustainability in nature indicates the sustainability of the ecosystems that support them and the sustainability of natural biological heritage.

The natural completeness of structural and functional diversity in ecosystems both determines and is a consequence of ecosystem sustainability. Biodiversity is the usual means by which ecosystem completeness, or integrity, is indicated (Stakhiv et al. 2003). Biodiversity is the variety of ecological forms and functions. Being a holistic concept, it is the source of all ecological resources and natural services (Norton 2006). Both ecosystems and biodiversity are hierarchically organized from the entire ecosphere down through ecoregions defined by differences in climate, dominant organisms, and river basins; through landscape, watershed and waterbody form and process; to local assemblages of species populations in biotic communities.

The most common unit of diversity used to describe biodiversity is species diversity—usually expressed as the number of species in a specified area (see Stakhiv et al. 2003 for a detailed review of diversity concepts and the related concept of integrity). But the distinctiveness of species populations is determined largely by a more basic unit of measure—the genes that uniquely define the populations. Because those genes collectively determine the unique structure and function of ecosystems, the

distinctiveness of populations that comprise the ecosystem community indicates ecosystem distinctiveness. Ecosystem security at the national level is indicated by the security of the genes in species populations. Both species and ecosystem security erode as species populations decline to extinction and natural heritage value is lost.

The opposite is true as well. Species and ecosystem security increases as populations are reestablished through ecosystem restoration. Because so much decline is caused by habitat loss, restoration and protection of naturally supportive ecosystems is the primary strategy used to reverse it. A species is considered secure from extinction when populations are restored to a number and distribution determined through technical assessment. Many species require several hundred populations (Stein 2008), but some require only a few. In the BSI, the fundamental unit of benefit measure is a viable unit of population, which may be an entirely new population or a secure increment added to an existing population. It could be a breeding pair in some species with naturally few populations. Thus, the basic currency of restoration results is a viable population unit ranging from a fraction to the entire population. Any monetary value (e.g., for commodities or recreational use) associated with the restoration of a population unit is irrelevant. The value is determined solely by the scarcity of ecological attributes desired by the public in a sustainable state as indicated in NEPA, the Endangered Species Act (ESA), and other legislation.

Even though species ranges and ecosystem boundaries overlap national borders, a political concept of national ecosystem sustainability and heritage value is useful for organizing national policy priorities for achievement of restoration objectives and the environmental sustainability goal of the Corps. These objectives and goals are consistent with the national heritage goals expressed in NEPA and other environmental law (Cole, in preparation (a)). As long as the natural and national boundary differences are recognized and accounted for, the concept of national ecosystem security also is consistent with a concept of global environmental sustainability based on maintenance of “natural capital” (Goodland and Daly 1996). The BSI is intended to indicate a contribution to securing natural capital and the full value of an intact natural heritage.

Whether the strategic goal is called national ecosystem security, environmental sustainability, natural capital, or natural heritage, the social basis of the goal is maintenance of options and opportunities for resource use

consistent with principles of sustainable development (Norton 1999). For cost efficiency, no more of an ecosystem is restored and set aside from destructive use than is necessary to confidently sustain future options and opportunities. The same concept applies here. The number of populations protected and recovered to viable status should be no greater than the number necessary to reasonably assure long-term continuity of the species. Similarly, at the project level, no more ecosystem structure and function are restored than is necessary to assure population viability in a project area. The reasoning is the same as that used to encourage cost-effectiveness in biodiversity conservancies: Much needs to be achieved with limited funding (Groves 2003).

Any investment beyond this minimum viability standard unnecessarily competes with value derived from present-day use, which is inconsistent with NEPA goals and sustainable development principles (WCED 1987). The BSI is based on the assumptions that the desired output value is nonuse value that cannot be acceptably measured in monetary terms. The nonuse value added is the greatest gain in species viability—population by population—per dollar invested. By indicating security based on global scarcity and threats, the BSI concept assumes that national ecosystem sustainability is best achieved by implementing plans that are likely to increase species viability globally. This may require international coordination for some species.

A regional approach could be an alternative to a national approach to framing the ecosystem sustainability objective and regional competition for funding is likely to favor it. However, surveys done by Stein et al. (2000), Chaplin et al. (2000), Cole (2010) and others indicate that need is unevenly distributed among regions and political boundaries, including Corps divisions. A national approach would provide funding more in proportion to the distribution of national need. The fundamental issue is cost-effectiveness. Because value added decreases as sustainability is approached, the regional alternative could be much less cost-effective nationally if the distribution of need varies greatly among regions. This issue does not diminish the importance of using ecoregional (e.g. Bailey 1995) or biogeophysical (e.g., lake, river, and coastal systems) classification schemes (e.g., Cowardin et al. 1979, Higgins et al. 2005) for organizing and managing inventories of potential projects and coordinating with others.

The BSI concept is developed incrementally in the following description, with increasing degrees of complexity added to the index for different applications. The most elemental form of the BSI is potentially useful for identification of Federal interest in the project during a reconnaissance study. Slightly more complex forms of the BSI could be used to rank projects for feasibility study investment in program-level planning. The most complete form of the BSI is calibrated during the feasibility study to be used for project implementation planning and to rank ecosystem restoration projects for implementation investment in program-level planning.

## Indicating achievement of biodiversity security

### Security status

The most basic form of the BSI measures ecosystem value based on the security status and a policy-determined weight for each species in each category of security. The security score for each species is summed to determine a BSI score:

$$BSI = \sum_{s=1 \dots n} (wG)_s$$

where:

$s$  = species  
 $wG$  = policy weighted indicator of  
 security status (G1-GX)

NatureServe Explorer Security Status (Conservation Status)	
G5	Secure
G4	Generally secure
G3	Vulnerable
G2	Imperiled
G1	Greatly Imperiled
GH	Possibly Extinct
GX	Presumed Extinct

G5	Secure
G4	Generally secure
G3	Vulnerable
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G1	Greatly Imperiled
GH	Possibly Extinct
GX	Presumed Extinct

The most basic indicator of value is species security status, which incorporates the concept of scarcity with respect to extinction and the desire of the public to sustain species as indicated in the ESA and other environmental law. Security from extinction is based primarily on global assessments of the number of viable population units remaining extant for each species (Stein 2008). The security status term requires dependable information about the level of security achieved for each indicator species. It also requires a policy decision about how to weight the relative importance of species at each level of security. Without designating another weight, a de facto weight of 1.0 is assumed and each level of security would be equally valued in any consideration of restoration and protection investment. In effect, projects with the greatest number of indicator

species would be selected regardless of their scarcity and threat of extinction. Most organizations would choose to apply a different weight, including the Corps because its planning policy guidance places great importance on resource scarcity in determining investment worth. Indicator species are limited to those relatively well-documented species with some potential for restoration in the project area. The indicator species are limited to vertebrates, mollusks, decapod crustaceans, and vascular plants. All species in these groups must be included in the BSI calibration to assure comparability across plans and projects.

The source of data for the inventory of security status and taxonomic status is the NatureServe Explorer database on species conservation status (NatureServe 2009) in the United States and elsewhere. The database is managed by and for national, state, and territorial natural heritage programs by the nongovernmental organization NatureServe. Security status is indicated by conservation status in seven categories: presumed extinct (GX), possibly extinct (GH), greatly imperiled (G1), imperiled (G2), vulnerable (G3), generally secure (G4), and secure (G5).

For all extant species, the conservation status number indicates a level of security; e.g., G5 species are most secure from extinction and more secure than species in all lower ranks. The rank number is not intended to indicate relative security in a linear way; i.e., G5 species are not five times as secure as G1 species. The security rank is determined primarily by species rarity and vulnerability, which is indicated primarily by the existing number and distribution of viable populations generally secure from extinction. Viability is evaluated using actual measurements of population trends, various population indicators of future trends (e.g., reproductive status), and predicted level and intensity of future threat.

Critically imperiled (G1) species are extremely rare with less than six viable population occurrences (Stein 2008). Imperiled (G2) species are a bit less rare with about 6 to 24 viable populations. Vulnerable (G3) species are uncommon and have 25 to 96 viable populations. Generally secure species (G4) are common but bear watching (97 to 384 viable population occurrences). Secure species are common, widespread, and abundant (385 or more viable populations). The progression clearly indicates that the number of populations in extant species needed to secure the next level of security increases by a multiple of 4. This progression also indicates the relative need to restore a species to a secure status. Detailed

information is provided at the NatureServe Explorer website (NatureServe 2009) and by Stein (2008) and Faber-Langendoen et al. (2009).

The indicator species make up less than 5% of the total number of species documented in the United States, but a very large fraction of the species ranked vulnerable to critically imperiled in NatureServe Explorer are in this group. Taxonomic data on the indicator species are generally thorough, although some change in status can be expected as new data emerge. Knowledge about conservation status and threats is more variable. Species of recreational and commercial value are usually among the most thoroughly documented. Terrestrial indicator species are typically better documented than freshwater or marine indicator species. While some subspecies are categorized, documentation of subspecies status is limited and biased toward terrestrial vertebrates, especially birds and mammals. Data quantity and quality are continuously improving, however, and the database is updated as new information becomes available. The database allows continuous review by authorities on conservation status and updating as justified based on advances in knowledge.

### **Policy weights**

Most users of the BSI will want to assign a priority to some categories of conservation status over others rather than accept equal emphasis in de facto weight of 1.0. If priority is desired, each category needs to be multiplied by a weight proportional to the priority set by organizational policy. There is no “scientifically correct” way to set priority weights on conservation status. Policy weighting typically depends on the statement of project and program planning goals and objectives, and the will to achieve them, but it can be influenced by other factors. Science can inform policy weights, however. For example, the numbers of populations needed to change the security status rank of a species also indicate the effort needed to restore the species. An agency without other constraints or interests might elect to weight strictly based on the population need.

Different missions and capabilities are a factor, as well as the potential for coordinating efforts across organizations. The Corps, for example, could choose to limit its priorities to species ranked G2 and above, leaving most of the more imperiled and possibly extinct species listed under the ESA to the Departments of Interior and Commerce. Or, species that are listed under ESA protection might be removed entirely from consideration other than the Departments of Interior and Commerce (that choice would

require a multiplier of 0 to exclude or a 1 to include based on the listing status of each species).

Table 1 contrasts various weight applications in examples based on different policy emphases. The first example (Column 1) places equal weight on all species in extant and possibly extinct species, perhaps justified by a desire to restore natural species diversity regardless of species vulnerability to extinction. In this case, a positive weight is placed on the possibly extinct category because there is a small possibility that extant member populations of the original community might ultimately be secured. Others would weight it 0 because of the risks. Risk of failure associated with restoration of the presumed extinct species is usually high enough to preclude it from any consideration, so it would typically be weighted 0.

Table 1. Policy-weighting examples that might be considered for guiding investment in ecosystem restoration based on various policy emphases pertaining to biodiversity security. Weighting is normalized to produce similar totals for easier comparison of the examples.

Conservation Status	Policy weighting examples			
	1 For native species diversity	2 To secure species proportional to population need	3 For imperiled species	4 For vulnerable species
GX Presumed Extinct	0	0	0	0
GH Possibly Extinct	12	0	10	0
G1 Critically Imperiled	12	48	40	0
G2 Imperiled	12	16	20	10
G3 Vulnerable	12	4	0	40
G4 Generally Secure	12	1	0	20
G5 Secure	12	0	0	0
Total	72	69	70	70

Alternatively, policy could set priority in proportion to the number of populations that need to be secured to a G4 or G5 status. The weighting used in Column 2 is intended to be roughly proportional to the numbers of populations needed to increase to the next level of security status in the NatureServe Explorer database based on the description by Stein (2008). The status changes geometrically by population multiples of four, i.e., about four times the number of G3 populations are required to restore G2 species to a G4 status and about 16 times is required to restore a G1 species to G4

status. The example in Column 3 places disproportionately more emphasis on imperiled species, including some emphasis on species that are probably extinct. In the last example (Column 4), imperiled species are judged to be disproportionately complicated and are left to more capable specialists in other programs. They choose to concentrate instead on reversing the decline of more secure species toward a more imperiled status (and possibly the need to list them under ESA protections).

Table 2 indicates how the scoring (score times policy weight) of one hypothetical community with 137 indicator species would vary based on weighting according to each of the four policy guidance examples indicated in Table 1. In this hypothetical community, over 45 percent of the indicator species are categorized as G3 and lower (a common condition in many American rivers [Cole 2010]). As the examples show, the choice of policy makes a significant difference in community scoring. Where all but the most definitely extinct species get equal weight regardless of conservation status, as in Column 1 of Tables 1 and 2, a community could accrue a significant score based on native diversity alone. Because most species nationally are generally secure (G4) to secure (G5), this policy would direct significant funding toward communities that have nationally secure species. Groups interested in restoring biodiversity locally without concern for global scarcity might select this approach. However, the restoration would not add nearly as much to securing the biodiversity of the Nation as the other policy scenarios.

All of the other scenarios (Columns 2-4 in Table 2) have weights with an emphasis on species that are to some extent insecure (G1-G4). For this particular community composition, policy weighting for imperiled species (where imperiled species are relatively few) results in a total score less than a policy that weights vulnerable species high. The total scores would reverse in another community with a high proportion of imperiled species.

Table 2. Policy weighting examples of Table 1 multiplied by the number of expected indicator species in each conservation status category of an ecosystem planned for restoration in a hypothetical project area. Total scores are determined by multiplying each indicator species by the conservation status weight used in Table 1 and summed over all indicator species in all conservation status categories

Indicator Species			Policy weighting example			
Conservation Status		#	1 For native Species diversity	2 To secure species proportional to need	3 For imperiled species	4 For vulnerable Species
Presumed Extinct	GX	1	0	0	0	0
Possibly Extinct	GH	3	36	0	30	0
Critically Imperiled	G1	5	60	240	200	0
Imperiled	G2	18	216	288	360	180
Vulnerable	G3	35	420	140	0	1400
Generally Secure	G4	30	360	30	0	600
Secure	G5	45	540	0	0	0
BSI Score			1767	698	590	2180

Relatively small differences in the proportion of conservation status groups can make substantial differences in score when the policy emphasis is highly focused as it is in the last two policy examples in Table 2. A greater policy focus on specific conservation status improvement results in greater project benefit discrimination when needed. It makes less difference when weighting is more generalized as it is in the first scenario. These examples indicate the importance of weighting consistently to compare across projects and programs.

Table 3 demonstrates how a program policy that consistently favors high weighting of vulnerable species would score projects with four different indicator species compositions, including the hypothetical community in Table 2 (Column 1 of Table 3). The examples demonstrate the importance of the total number of indicator species in an anticipated community. A community with few indicator species can rank low despite having a high fraction of all species among the positively scored species (Community 3 in Table 3). All else equal, communities with a high number of indicator species will rank higher than communities with a low number of indicator species.

**Table 3. Scores generated by applying a program policy that consistently favors restoration for vulnerable species (the last column in Table 2) to four hypothetical communities, including the community basis for Table 2.**

Conservation Status	Hypothetical Community							
	Community 1 (from Table 2)		Community 2		Community 3		Community 4	
	Sp #	Score	Sp #	Score	Sp #	Score	Sp #	Score
Presumed Extinct	1	0	0	0	1	0	0	0
Possibly Extinct	3	0	1	0	2	0	0	0
Critically Imperiled	5	0	30	0	2	0	2	0
Imperiled	18	180	30	300	14	140	9	90
Vulnerable	35	1400	25	1000	11	440	45	1800
Generally Secure	30	600	20	400	8	160	85	1700
Secure	45	0	32	0	7	0	125	0
Community # / BSI Score	137	2100	138	1700	45	740	267	3590

This simple, most basic form of the BSI concept can be used to screen for Federal interest. Sites with 0 score would not qualify for investment. It could be used to set priorities for project feasibility study investments. The projects would be ranked for their potential contribution to national ecosystem restoration based on a score derived from all of the insecure indicator species in the anticipated project area. This metric has much more discrimination power than a simpler criterion based only on whether or not any species of special status is present in the anticipated project area. Use of the metric for ranking budget allocation for feasibility studies would place great emphasis on restoring ecosystems in “hotspots” of biodiversity insecurity regardless of how distinct the species are from one another.

This basic form of the BSI is relatively simple to calibrate and use but ignores important differences in biodiversity that occur within and across species populations because all species populations do not contribute equally to genetic diversity. If species and community genetic distinctiveness is an important aspect of program goal and objective achievement, it needs to be included in the metric as well. Because natural heritage includes all of the variety in nature, including distinctiveness in the metric should be preferable to the Corps if the data for calibration are readily available.

## Distinctiveness

The second form of the metric concept includes an indicator of ecosystem distinctiveness based on the distinctiveness of species populations,  $wD$ , comprising the community anticipated in the project area:

$$BSI = \sum_{s=1...n} ((wD)(wG))_s$$

where:

- $s$  = indicator species
- $wG$  = policy weighted indicator of species security status (G1-GX)
- $wD$  = policy weighted indicator of species distinctiveness

Communities and ecosystems with more genetically distinctive species are more biologically distinctive than other communities and ecosystems. Genetic differences result in structural and functional differences that could contribute differently to the maintenance of future opportunities for resource use and development. Without any other information available, the human-caused extinction of a species with numerous unique genes is generally assumed to be more likely to deprive the future of greater heritage value than human-caused loss of a species with fewer unique genes. Sustaining genetic diversity (if not precisely the same genes) sustains potential for diverse utility, if not exactly the same utility.

Modern technology allows the potential for developing quite detailed knowledge of ecosystem genetic makeup and the detection of potential genetic loss with population and species extinction (e.g., Frankham et al. 2002). However, a small percentage of species genetics is now documented. That knowledge should become much more important for future planning purposes, but for now is insufficient for practical applications. Meanwhile, a simple indicator has been developed for the BSI to approximately estimate genetic distinctiveness found in biotic communities based on taxonomic classification at the species and genus level.

At this time, the species level is the lowest division that is practical to use in the distinctiveness index because sub-specific taxonomy is unevenly documented across species and is an unreliable indicator of sub-specific distinctiveness. Higher levels of taxonomic classification (e.g. family,

order) could be used as well, but the value added appears not to justify the additional complexity. Assuming that there is a reasonable relationship between taxonomy based on distinctive traits and genetic differentiation, the numbers of species in a taxonomic family is an indicator of population distinction. At the extreme, for example, securing a species that is the only member of its taxonomic family very likely secures more genetic diversity than securing a species that is one of 30 species in its family. Information on the number of species in its taxonomic family is widely available in NatureServe Explorer and other sources.

For the above example of one species in its family, the index would be  $1/1$ , or 1. For the second example, it would be  $(1/30)$ , which equals 0.033. This result would then be used for the distinctiveness term,  $wD$ , for each species in the community. In this example, a species that is the only member of its family would have 30 times the weight of a species that is one of 30. Assuming a policy weight of 1.0, a species in a family with more than one member will have a term value that reduces the species score based on the weighted security term alone in proportion to the number of species in the family. As contemporary methods become more widely and less expensively applied, a more robust indicator of distinctiveness could be developed from molecular evidence of genetic difference (e.g., Frankham et al. 2002).

Using the distinctiveness term as described, communities composed largely of closely related species would not compete well for restoration attention with communities composed of distantly related species of the same security status. Many freshwater mussel species are greatly imperiled (G1), for example, but imperilment is concentrated in a single family with numerous species. The Socorro isopod (*Thermosphaeroma thermophilum*), on the other hand, was found naturally in one geothermal spring system (may now be extant only in captive populations) and is the only member of its family in North America. Based on this criterion alone, the recovery of an isopod population through ecosystem restoration would generate substantially more heritage value than the restoration of the typical freshwater mussel population.

The de facto distinctiveness weight of 1.0 may be adjusted by a policy decision to increase or decrease its influence on the score and it could be eliminated entirely if a user chose to do so. There is no a priori reason that its emphasis should equal that of the species security weight, but a different

weight should require considerable thought about the rationale. Community distinctiveness is usually considered in the priority protocols of biodiversity conservancies, but not necessarily with equal weight (Groves 2003; Cole, in preparation (a)). It plays no formal role in setting listing and recovery priorities for populations under the Endangered Species Act. The final determination of the weight applied is a policy decision.

The data on distinctiveness based on taxonomic indication are readily available through NatureServe Explorer or other sources. Except for a small additional time factor, there is little reason not to include it early in the Corps ecosystem restoration planning process for reconnaissance study and project ranking for feasibility study budget allocation. But this form of the metric is insufficient for project planning needs.

## Project implementation ranking

### Overview

The metric forms so far described grossly indicate the potential for species population recovery at possible project site locations, but nothing is revealed about the estimated valued added by specific project plans. A feasibility study allows the calibration of several new terms that cannot be included in benefits estimation in the earliest planning phases. These terms are included in a more advanced form of the metric useful for evaluating the benefits of implementing ecosystem restoration measures:

$$BSI = \sum_{S=1 \dots n} (h(wR)(wD)(wG)(A_1 - A_0))_s$$

where:

- $s$  = indicator species
- $A_0$  = initial number of viable populations
- $A_1$  = final number of viable populations
- $wG$  = policy weighted indicator of species security status (G1-GX)
- $wD$  = policy weighted indicator of species distinctiveness
- $wR$  = policy weighted indicator of risk of species population restoration failure
- $h$  = indicates authority to address threat (0 or 1)

The specific number of viable populations established in the project area is most basic to benefit estimation for project plans ( $A_1 - A_0$ ). An indicator of relative value added by a project plan can be developed from the multiplication of the number of species populations and their policy weighted security and distinctiveness terms. However, that simple metric would assume that the risk of failing to restore populations is 0, or risk would need to be addressed elsewhere in the planning process. Ignoring the risk would overestimate the value added by many projects. The metric promoted here includes a risk term expressed as a probability of success. In addition it includes a simple term for indicating whether or not the restoration agency is authorized to address the threat. The value is 0 when lack of an authority is limiting and 1 when it is not.

### **Viable populations**

A viable population is defined here as an assemblage of individuals that exchange genetic material through reproduction, are genetically similar, and are likely to persist for the long term in a stable support-system context. Viable populations stand more or less apart from other populations, but often with some tenuous connection to other populations allowing small amounts of population exchange. Viable populations typically exhibit general stability in population structure, birth rates, and death rates. The stability indicates security from local extinction of that population. More general information pertaining to conservation planning can be found in Stein (2008) and Faber-Langendoen et al. (2009).

Each species has specific requirements to establish minimum viable population numbers. Substantial work has been done in this area, but is limited largely to vertebrate species. Estimates vary for minimum viability in part depending on criteria used. Early estimates, based on the number of breeding adults required to avoid inbreeding and genetic drift, was at least 500 individuals (Franklin 1980, Soule 1980). More recent estimates have tended to increase the estimate of viable breeding population size (Allendorf and Ryman 2002) by more than an order of magnitude (Reed et al. 2003). Very large species tend to require lower numbers than smaller species.

Estimates depend largely on the security level desired (the desired probability or certainty of viability) at some specified future time based on number of generations. Reed et al. (2003) made their estimate of 7,000 breeding adults based on realizing a 99 percent chance of lasting 40 generations. A population about one tenth that size would have a

50 percent probability of lasting that many generations. Most work has been done on relatively large animals. Belovsky (1987) estimated minimum viable population size of mammals the size of shrews to be close to 100,000 individuals while 400 may be sufficient for animals the size of elephants. Estimating minimum viable population size is one of the more difficult aspects of metric calibration and will usually require special expertise. The usual approach is to evaluate the stability of extant populations. A practical approach is to determine the habitat size and characteristics needed to sustain the smallest stable populations already existing elsewhere. That could establish a minimum project size for the species population, which could be adjusted upward to offset the uncertainty of the estimated size of a viable population.

A project plan may start with no members of the population in the project area or with some remnant of a population that is no longer viable. Ordinarily plans that indicate restoration of either contribute equally to the metric. The final condition of viability is what counts in the score. But there are exceptions. For some larger, highly mobile species, only a few identifiably different populations occur in the entire nation (the bald eagle, *Haliaeetus leucocephalus*, is a good example). Typically, a single restoration project can only aspire to add a fraction to the population. Reestablishment of a reproducing pair in a project area more certainly indicates long-term contribution to population viability than a single individual. For these species, the fraction of the entire population that is expected to be restored in the project area is calculated and the fraction is included in the species score. Other species are naturally limited to a single population within a small habitat, including many freshwater-spring snails, crayfish, and small fish species. When those species begin to decline, restoration ordinarily would target recovery of a fully viable population.

The BSI accounts for all populations in the project area that will be affected directly by project-generated changes as well as populations outside the restored project area that are expected to colonize it (with or without human help) once the project is implemented. The area may harbor vulnerable species populations that could be negatively impacted by implementation of planned management measures. The BSI sums for both positive and negative impacts.

A population-based approach would be desirable for all levels of decision-making, including the reconnaissance phase. However, the detailed

information on populations and their status existing at and around particular project sites is not as easily retrieved as the data on species conservation status and species level taxonomy. The effort will usually require substantial investment of time and money during the feasibility study, and the enlistment of ecological specialists.

### **Managed and residual risk**

Risk is the probability of undesirable project outcomes—i.e., desired populations do not achieve a viable status. Risk derives from uncertainty, but not all uncertainty is undesirable. However, the uncertainty associated with failure to restore a viable population is largely undesirable.

Uncertainty exists both in estimating numbers and structure required to establish a viable population and the environmental requirements for establishment. Underestimating the numerical, structural, and environmental needs for population viability leads to failure. Overestimating needs leads to unnecessary redundancy, greater than necessary costs, and more limited program success.

Conventional risk and uncertainty analysis relies on statistical techniques to define statistical distributions around a statistical population mean or median value. That portion of the distribution that is undesirable provides the basis for calculating a precise probability of the risk based on the assumption that past conditions determining the statistical distribution will repeat themselves closely. Rudiments for this type of analysis have been provided in reports designed specifically for measuring environmental outputs from Corps projects (Yoe and Skaggs 1997, Diefenderfer et al. 2005). The analyses are very useful when historical data sets are available, but are less useful otherwise. Because many important aspects of the risks of project failure often do not have the appropriate record, a more qualitative approach must be used to evaluate risk.

No project plan can completely account for and manage all risk of failure to produce the desired outputs and benefits. Even the best risk management plans leave a residual risk of failure. The most advanced form of the metric includes a weighted term,  $wR$ , for the risk that restoration measures as planned will fail to restore targeted population units to a viable status. The risk term is expressed as a probability of success. Because of data limitations, the probabilities of success are approximated in low, medium, and high risk categories represented by 0.9, 0.5, and 0.1 probabilities of success. Managing risk requires analysis

of the risk pathways, which need to be identified and addressed through plan formulation. Common pathways for risk are the basis for estimating residual risk and calibrating the risk term. The probabilities for all pathways are averaged to determine the risk term probability.

Ecosystem restoration project plans are basically risk management plans that set out to eliminate the barriers to reestablishment of desired outputs and associated benefits in the proposed project area. Therefore risk sources should be considered in plan formulation. The EQ restoration authority is based on the assumption that much of the risk can be managed effectively. But some residual risk is unavoidable. Because risk management information usually is not easily accessible before a project feasibility study, risk analysis ordinarily contributes little to reconnaissance decisions or ranking feasibility studies in program budget plans. However, residual risk information is essential for implementation decisions, including priority assessment for project implementation investment at the program level. A program that ignores risk in priority decisions is likely to be less cost-effective.

The risk term is a composite indicator of risk facing restoration of each population. A fully quantitative index requires estimates of risk probabilities, many of which cannot be estimated precisely at this time because of insufficient and highly variable data. For now, the emphasis should be on identification of risk sources and general categorization of high, medium, and low risk levels. Until the sources are better understood, a simple average of all risk indicators is as justifiable as any other alternative for calculating the composite risk term. The key point is that risks are carefully assessed across the program using the same standards. This requires substantial work, which is one reason why risk is often cursorily considered in project planning. An organization may decide on a policy to weight risk higher or lower in importance than the other terms after careful consideration.

The risk term is the most challenging of the BSI terms to calibrate. Ecosystem restoration risk assessment is more complex, for example, than flood damage reduction risk assessment, which relies on quantification of a fewer, more easily measured variables. Ecological risk, at least at this stage, must be approached more qualitatively. The concept will undoubtedly evolve and mature with increased understanding of ecosystems and their responses to ecosystem restoration methods.

Substantial progress already has been made through the disciplines of conservation biology, landscape ecology, and restoration science. Many of the risks faced by ecosystem restoration for national biodiversity security are the same as or similar to those faced by biodiversity conservancies when they design conservation areas to preserve biodiversity.

### **Important risk pathways and sources**

The risks of not achieving project and program objectives cost-effectively come from many sources through a number of pathways. Pathways for more common risks at Corps restoration projects include:

- Insufficient geophysical restoration
- Incomplete control of all limiting factors
- Incomplete connectivity of the project area to intact sources of materials and colonizers
- Future instability of presently intact ecosystem sources of materials and colonizers
- Presence and effects of non-native species
- Incomplete consideration of the scale of threatening events
- Incomplete knowledge of more cost-effective alternatives

Risk sources can be identified through careful questioning, as illustrated below, about the project area condition, the surrounding ecosystem context, and the larger context of national biodiversity protection and restoration activities.

*Is the geophysical restoration complete?* A geophysical condition short of habitat need in the project area will limit the recovery of desired species and their supporting communities and ecosystems (e.g., Wissmar and Bisson 2003). Marginal gains of more natural hydrology and geomorphology may not be enough to provide the required conditions to sustain all of the species population units that justify the project. Risk from this source usually approaches zero as all human impact is removed, but, because much human impact is irreversible, some risk of this kind is usually unavoidable. To be complete, geophysical restoration must extend beyond the usual measures of natural runoff amounts, hydrodynamics, and topography to local hydraulics and composition of soil, sediment, dissolved solids, hydraulics and other micro-structure and process. Study of existing viable units of species in natural references is very useful for determining both geophysical habitat quantity and quality needs. Because

removal of human effect is often socially or economically unacceptable, simulated geophysical naturalness is a common alternative, which, by its very nature, is incomplete and has associated risks. Simulation typically requires maintenance, and associated risks are less commonly encountered with full restoration of natural geophysical processes. Estimated maintenance cost is one indicator of maintenance extent and risk.

*Are all limiting factors managed?* Although geophysical restoration may be complete enough, it may be insufficient if other factors are also limiting in the project area. Sources of intolerable water quality can act somewhat independently of hydrology and geomorphology. Too much or too little input of inorganic sediment, nutrient, and organic matter can have major impacts on communities despite apparent recovery of a supportive hydrology and geomorphology. Intensive harvest of habitat-influential and community-influential species, such as oysters and forage fish, can result in highly altered habitat and community conditions that limit recovery of desired biological resources. A key strategy here is to incorporate into the planning process ecosystem and population models that are comprehensive enough to evaluate restoration effectiveness. Another strategy is collaboration with all agencies necessary to have the authority to remove limitations. Most risk of this sort can be managed in many situations, but residual risk grows in environments that have been extensively and diversely impacted. Extreme but normal events—such as hurricanes, freezing, drought, fire, disease—are difficult to manage during the particularly sensitive restoration period when they can be destructive and should be included in the risk assessment.

*How well connected are project areas to intact ecosystems?* The degree and consistency of historical connectivity restored between the project area and the nurturing ecosystem context determine the recovery rate and completeness in the project area. Reestablishing connection to biological resources in surrounding ecosystems is essential for restoration of ecosystem support (e.g., Ndubisi 2002, Naiman et al. 2005). It also is essential for reestablishing needed flows of nutrients, organic matter, and other material into and out of the project area so as to sustain the ecosystem support. It may be appropriate for establishing optimal ingress of desired species members into the geophysically restored project area, although too much connectivity could preclude reestablishment of independent populations. Barriers to organism and materials movements can be physical, chemical, or biological, and natural or unnatural.

Unnatural connectivity, such as canals, can also be pathways of threats to natural biodiversity, such as non-native species. Risk of project failure grows with the number and extent of human-caused changes to connectivity. Risk is managed by restoring ecosystems adjacent to an intact dispersal source of colonizing populations and, when more remote, assuring that the restored connections function like the fully natural condition. Risk is indicated approximately by the distance of the project area from colonizing sources and the extent to which fully natural connectivity has not been achieved.

*How stable are the sources of restored ecosystem materials and colonizers?* The stability of the natural ecosystems that serve as sources of nurturing materials and colonizing organisms is critical for long-term sustainability of the restored ecosystem and desired species in the project area. Stability is sustained by natural events and processes occurring as they have historically in similar intensities, frequencies, timings, and durations. Stability generally requires continuity of past climate variability and land and water condition and ecosystem scale large enough to absorb local perturbations without altering the species dispersal rates by much. Possible changes in climate make full restoration of hydrology and materials transport less certain everywhere, but more so in some places than others (Naiman et al. 2005). Risk is typically elevated by climate change where aquatic and terrestrial ecosystems meet in shallow waters and nearby shores. Topography is important. For example, seashore restoration projects on nearly flat coastal plains may be riskier ventures than on steep shorelines, because even small changes in sea level on flat shores can affect large areas. Flood events are likely to have more extreme effects on flood-plain and island ecosystems. Droughts are more likely to have extreme effects on shallow-water ecosystems. Risk of damaging land use changes to watershed condition increases with proximity to human population centers and where land is privately owned, but is moderated where state laws and enforcement assure impact minimization. Much of risk management has to do with locating projects and restoring at a scale that can assimilate uncertainty in anticipated boundary conditions.

*Will harmful non-native species invade?* Many American ecosystems have been invaded or are threatened with invasion by non-native species (Pimentel et al. 2000, Cole 2005). The impact of non-native species on native biodiversity varies widely. Many have had little observed negative or positive impact on native population viability. A few have become

ecological dominants. They can have major negative impacts on species composition (positive effects on native species are rarely observed). Knowledge of their distribution, tolerance of restored conditions, probability of invasion, and negative impact is essential. Good evidence of limited risk is rigorously documented coexistence of non-native species with native species in the colonizer-source ecosystems. Risk is typically managed by avoiding project areas that are likely to become dominated, blocking access in ways that do not threaten achievement of the project restoration objectives, or by selectively removing the invaders once they gain access. However, all of these management actions include substantial residual risk of failure, which needs to be carefully assessed for the metric.

*Is the geographic scale of the project proportional to disturbance?*

Geographic scale is a critical consideration (Ndubisi 2002). Many aquatic ecosystems are sustained by extreme natural events such as hurricanes, fires, floods, droughts, and outbreaks of disease. The life cycles of many aquatic and riparian species are adapted to seasonal cycles and entire ecosystems come and go with more intense floods and storms in river and coastal environments (Naiman et al. 2005). Ecosystems are sustained because the temporal and spatial pattern of the events both create and destroy nurturing geophysical conditions, including connectivity between old and new. In this dynamic, restoration that is planned at the scale of the events is more likely to succeed than restoration planned at a smaller scale. In general, risk is managed by restoring the supporting ecosystem to a scale at which events operate to sustain physical environments. This must be coordinated with connectivity management that facilitates the spatial dynamics needed to adapt to the events. Restoring an isolated floodplain remnant in the middle of a city, for example, is much less likely to sustain insecure biodiversity than restoring an entire floodplain to natural flood regime and landscape patterns in several tributaries upstream from major development. Where accentuated flooding is an issue, for example, restoring habitats in two widely dispersed tributaries of a large river is more likely to manage the risks faced by flood-sensitive species from the most common flood events than restoring habitats in the same tributary. Event interactive changes in the watershed or other regional context need to be considered for their potential modifying effects. Anticipated watershed alteration and effects of climate change are major considerations.

*Do more cost-effective alternatives exist?* Ecosystem restoration generally is a more expensive and more risky alternative to protecting existing biodiversity than protecting existing ecosystems. Restoration is usually a strategy of last resort for biodiversity conservancies (Dinerstein et al. 2000, Groves 2003), but one that is considered essential where much of the natural condition has been radically altered. Policy largely limits ecosystem restoration to reestablishment of more natural geophysical form and process (including vegetation) in amounts and systems context appropriate to cost-effective recovery of significant natural resources. The Corps risks cost ineffectiveness at the larger level of government spending when there are many ecoregional opportunities for recovering those same resources at less expense. The most important strategy for managing this risk is collaboration in regional and national planning with clearly stated biodiversity objectives and management measures. A careful programmatic comparison of project risks would consider the relative risks anticipated from all projects, including those sponsored by parties other than the Corps. Such comparison requires an ecoregional inventory of other project possibilities and activities of agencies and NGOs with similar missions. This risk is especially important to consider because there is no clear bright line determining when the benefit from a project plan does not justify the investment. That “line” becomes clearer when there are many other locations where the same results can be produced much less expensively.

#### **Authority to address threat**

An organization or group of collaborators may not have the authority to address the threat faced by a population in the project area. For the Corps of Engineers, which derives its authority for restoring ecosystems through the geophysical environment (hydrology and geomorphology of rivers and coastal zones), whether or not the geophysical attributes of habitat are limiting community recovery is an essential consideration for investment. While it is generally understood that most threats to species operate through altered habitat, the source of threats is not clearly determined for many species and needs to be determined during the analysis of risks and their management. For the Corps, the value for the term  $h$  is determined by whether or not habitat is the limiting factor (1 for species limited by habitat and 0 for all other limiting factors). However, the Corps and other organizations can collaborate to provide the needed authority in most instances.

### **Spreadsheet approach to metric calculation**

Table 4 provides an example of how a BSI is calculated in a spreadsheet. In this hypothetical community, the security and distinctiveness of indicator species are equally weighted. The policy weight for security status emphasizes restoration of species in proportion to the number of populations needed to recover the species to a secure status. Three of the species are expected to have more than one viable population added by the selected plan. Several indicator species are ranked 0 in Table 4 because policy determined that secure (G5), possibly extinct (GH), or presumed extinct (GX) species should not receive any attention, either because they were already secure or they were impossible to recover based on existing knowledge of the species. For one population, the organization did not have the authority to address the threat that reduced it to a nonviable status. Another species has very few widespread natural populations and only a small fraction of a population can be restored within the project area. It contributes very little to the overall score primarily because it contributes so little to population and species viability.

The example community has a low number of indicator species. Communities in many settings would have much larger numbers of indicator species. Even so, spreadsheet calculations are simple once all of the terms and their policy weights have been calibrated.

### **Cost-effectiveness**

The BSI is a benefits indicator only. Because investment funds are limited, it makes little sense to invest in plans of higher cost that have the same benefits, or to rank projects for budget priority based on project cost differences. This is recognized in the programmatic authority for environmental quality restoration provided in WRDA 1996, which requires “cost-effective” restoration of environmental quality. Cost-effectiveness analysis is addressed in project planning (USACE 2000) and budget guidance (USACE 2009). The same general approaches now used to estimate cost-effectiveness can be used with the new metric.

Table 4. An example of the calculations used in the advanced form of the BSI to determine a total score by summing the indicator species scores of a community anticipated in a hypothetical project area. In this example, the weighted distinctiveness ( $wD$ ) and risk ( $wR$ ) were left at the *de facto* weight of 1.0. The weighted security status ( $wG$ ) reflects a policy based on the number of populations needed to recover the species in each status category to a secure status.

Species	Population Number	Security Status	$wG$	$wD$	$wR$	$h$	Total Score
1	1	G2	16	0.500	0.5	1	4.000
2	1	G5	0	--	--	--	0
3	2	G1	64	0.012	0.3	1	0.461
4	2	G3	4	0.020	0.6	1	0.096
5	1	G2	16	0.005	0.8	1	0.064
6	0	G3	4	0.110	0.4	0	0
7	1	G4	1	0.009	0.9	1	0.008
8	1	G5	0	--	--	--	0
9	2	G5	0	--	--	--	0
10	0.001	G5	16	0.300	0.7	1	0.003
11	0	GH	0	--	--	--	0
Biodiversity Security Index							4.632

Cost determination is possible only after all plan alternatives have been formulated and therefore applies to recommendations made from feasibility studies for plan implementation in the construction phase and to setting priorities for annual budgets.

Cost-effectiveness is a key principle in the Office of Management and Budget (OMB) program management guidance (OMB 1992) when economic benefit-cost analysis is not feasible. OMB would prefer an estimate of the fractional achievement of the program goal. That requires quantification of the program goal (which makes it an objective in some definitions). With respect to this metric, the measure of program goal achievement is the total population viability required to achieve G5 status for all species (a less aggressive objective could be G4 status). This requires a complete assessment of all species, which is possible to do based on existing information in the NatureServe Explorer database. The result is likely to show that each project and annual investment will typically add small increments of viability to a very large total need. While that is meaningful from the standpoint of indicating the dimensions of

investment needed to achieve the ultimate goal, it adds no more information for setting annual funding priorities and is therefore not included in the metric. It may be useful secondary information for conveying the scope of the program challenge, however.

## 4 Discussion

### Biodiversity-based indication of benefit

The Corps has sought unifying concepts for its measurement of environmental benefits ever since it received authority to plan for environmental improvement in 1965 (Stakhiv et al. 2003; Cole, in preparation (a)). Full monetization has not been acceptable for either cultural or ecological benefits associated with public bequests in the form of cultural and natural heritage (USACE 2000). Resolving differences in cultural and ecological benefits may be intractable, but restoration benefits are limited to ecological resources. Because biodiversity is the source of all ecological resources and natural services (Norton 2006), a large part of the qualifying value for ecosystem restoration investment by the Corps appears to be captured in the concept of national biodiversity security. A close reading of the Federal project planning and project study objectives presented in guidance (USACE 2000) reveals no type of benefit other than biodiversity-based heritage as a justification for restoration project investment.

Biodiversity is a comprehensive concept (Heywood 1995). The biodiversity of ecosystems has been likened to a library, bank, or warehouse holding stores of information and potential resource opportunities (e.g., Wilson and Peters 1988); in other words, a natural biological heritage. The public has shown its desire to sustain national natural heritage in the objectives of environmental law, such as the NEPA and ESA. The value added by projects can be demonstrated by the reduction in heritage resource scarcity with respect to the public demand for its sustainability. The BSI is based on this concept of resource scarcity.

There is little doubt that the objective achievement indicated by the BSI is worthy. The need for securing and sustaining natural biological heritage expressed in native biodiversity is widespread and may be increasing. The security of species-based biodiversity in natural ecosystem contexts has decreased rapidly during the past century and, by numerous accounts (e.g., Wilson and Peters 1988, Reid 1997), continues to be threatened, especially in freshwater ecosystems (Richter et al. 1997, Ricciardi and Rasmussen 1999, Abell 2002, Cole 2010). There are few if any freshwater resources that the Corps and other agencies have developed that do not

have at least one species ranked as G3 or higher (Cole 2010). Incidental to biodiversity security, many ecosystem services are secured, including the value of many goods and services that can be measured in monetary terms (e.g., Barbier et al. 1995). The protection and restoration challenge is great and the collaboration among organizations is essential (Groves 2003).

An ecosystem resource assessment approach that is consistent with use of the BSI and common in conservation biology includes 1) identifying species insecurity level and restoration risks at an ecoregional level to coordinate improvements across the region, 2) ranking prospects based on cost-effectiveness, and 3) eliminating projects that are obviously too cost-ineffective (Dinerstein et al. 2000, Groves 2003). Ecoregional planning is well advanced for terrestrial diversity protection; more so than for freshwater considerations. Freshwater emphasis is growing with realization of the large discrepancy that exists in freshwater and terrestrial biodiversity protection. This awakening has resulted, for example, in development of general strategies for freshwater protection (Saunders et al. 2001) and a new classification approach for freshwater conservation planning (Higgins et al. 2005).

The umbrella strategies used to secure and sustain natural biological heritage are: 1) to protect native biodiversity from further loss by avoidance, minimization of effect, and compensation for effects generated by human actions, and 2) to restore native biodiversity in significant decline to a secure status in supportive ecosystem contexts when protection alone is inadequate. These strategies are based on the assumption that effective ecosystem restoration increases the security of native plant and animal species from human-caused extinction by securing their needs in the diversity of more or less natural ecosystem structures and functions. Ordinarily, protection of existing biodiversity is preferred because of the additional risks associated with restoration (Groves 2003), but too much degradation has occurred for protection alone to be sufficient in numerous ecosystems. The actions of organizations that specialize in protection need to be complemented in a coordinated way by organizations that specialize in restoration, such as the Corps. The BSI was designed specifically to measure natural biological heritage value added by restoration projects consistent with Corps EQ restoration policy, but, in concept, it could be used as well to make ecosystem protection-investment decisions directed at maintaining natural biological heritage.

Many different techniques have been developed to guide investment in the protection of biodiversity (e.g. Ferson and Bergman 2002; Groves 2003). They contributed largely to the selection of the BSI terms (Cole, in preparation (a)). Most of these techniques have to do with selecting conservation areas for protection using algorithms to most cost-effectively represent the entire ecosystem while assuring the rarest forms are protected with enough redundancy. These methods are designed to select from thousands of possible conservation areas, usually from natural landscapes. Restoration usually is a last resort in this process, but can be included based on projected biodiversity attributes of conservation areas (Groves 2003).

The Corp of Engineers faces a somewhat different planning problem than nongovernment conservancies because it is limited by its authorities to restoration actions and to evaluating for benefits from projects that it does not ordinarily select for feasibility study. The Corps is required to cost share with nonfederal sponsors, who often desire the restoration mostly for economic development and local interests, such as for recreational use and increased property value. In this context, the Corps has to make the best of not being able to select freely among the best possible restoration sites for adding value at the national level. That includes consideration of the ecoregional conservation emphases planned by biodiversity conservancies in inventories of project conditions during plan evaluation and in annual priority ranking (e.g., Chaplin et al. 2000). It also includes establishing a project ranking metric for annual budget allocation that clearly reflects the intents of the EQ restoration authority. The BSI is an attempt to conceptually respond to those intents.

## **Metric attributes**

The BSI is based in the scientific principles and management principles of conservation biology, including planning for biodiversity conservation (e.g., Groves 2003). The concepts and principles underlying the terms used in the metric are commonly encountered in conservation investment protocols and methods (Groves 2003) and in certain Federal laws (Cole, in preparation (a)). These same principles underlie the ecosystem-based approach to recovering threatened and endangered species listed under the ESA. Concepts of security status, distinctiveness, threat assessment, and viable populations have advanced rapidly and continue to evolve, but have become fundamental in conservation planning despite measurement imperfections (Belovsky 1987, Dinerstein et al. 2000, Ferson and Bergman

2002, Groves 2003). Like other metrics, insufficient information can be a limiting factor. The BSI can be refined, however, as information for calibration improves, such as more precise indicators of conservation status and increased availability of DNA data for indicating species distinctiveness.

Attributes of the BSI were developed to allow its common use for budget ranking and project planning in the Corps. As long as the same metric elements, database, and policy weights are used, the BSI is a widely applicable single indicator of value added by investment in project planning and project implementation. Because of the way the Corps budget is allocated, it is not necessary to use precisely the same form of the metric for ranking projects for feasibility study and implementation (construction). This is fortunate, because some of the information necessary for comprehensive evaluation of project plans for implementation requires a feasibility study. Forms of the metric developed for each of those phases can be compared across projects to rank the project feasibility study and construction contribution to national benefits.

One of the greatest assets of the BSI is its communication value internally and with other agencies and programs. It identifies value added directly based on restoration of species populations desired by the public in sustainable quantity. It does not rely on habitat units or other indirect indicators of benefits that cannot be applied uniformly across projects. Use of the BSI could be a major step toward reducing the number of monetary and nonmonetary metrics for ecosystem restoration planning to a more manageable few. After a period of familiarization, its general use should reduce past communication difficulties associated with the many different metrics used. Because of its directness, the BSI concept should be more easily understood by stakeholders involved in tradeoff considerations, including those concerned with sustaining biodiversity as well as those who are concerned about the displacement of present use to restore and sustain a secure natural heritage. An independently maintained, widely used, and generally accepted database, NatureServe Explorer, is available to inform stakeholders about technical issues pertaining to identification of federal interest, project evaluation, and project ranking in program budget planning.

Sustainability of the desired resources once restored is an essential aspect of the value added by restoration projects. Planning guidance emphasizes the need for long-term persistence of the desired outputs (USACE 2000). The concept of sustainability is inherent in resource conservation principles. Heritage value increases as the sustainability of project outputs increases across future generations. The value added based on the BSI is closely linked to the viability of the desired species populations in the context of a supporting ecosystem. Value is lost as the residual risks that face the restoration of viable populations increase.

In keeping with the emphasis on sustainability, the risk of project failure (the desired resources are not restored to a viable state) is included in the value indicated by the BSI. The rationale is simple: recommending risky projects will result in less benefit from program investments than if less risky but equally productive projects are recommended. The risk term is closely related to plan formulation, which can be viewed as a risk management process. However, plan formulation rarely results in complete management of all risk. Probability of project success is rarely certain. The risk term indicates the residual risk remaining once restoration measures are implemented. Thus the same principles for estimating residual risk are basic to effective plan formulation. The fundamental concept is believed to be sound, but its application requires concept refinement and expression in detailed protocols guiding the assignment of success probabilities to each species.

By no means should the BSI be considered more than a conceptual contribution toward more precise and accurate characterization of heritage value based on biodiversity security. Much remains to be learned about identifying viability of populations and species, especially with respect to how many populations and where they should be located to secure communities and ecosystems from erosion of their integrity at the national level. With that in mind, the BSI is intended to be a basis for continual improvement. The BSI is no exception, however. This caveat applies to all non-monetary indicators of ecosystem value being used by the Corps and others. Index improvement is likely to be a long-term process of evaluation and refinement, which should improve as knowledge about effective restoration improves, especially if rigorous concepts of adaptive management (Holling 1978, Walters 1986) are applied.

## Corps application

An ideal nonmonetary metric for EQ restoration value added by Corps projects would be consistent with Corps authority, commensurate and comprehensively applicable, easily understood by planning specialists, scientifically and socially acceptable, and practical. The extent to which the metric described here for indicating national biodiversity security meets these criteria has yet to be fully evaluated. Based on early analysis, however, the BSI concept shows promise for being a major advance over the present use of many different metrics that are often difficult to link to the value added by EQ restoration projects. It was developed for the interpretation of ecosystem restoration authority explained here and in Cole (in preparation (a)). Part of the process of vetting the BSI will include evaluation of the authority interpretation the BSI is based on with the consistency of that interpretation throughout the Corps.

The concept presented here is the proposed basis for developing a new tool that could change ecosystem restoration planning significantly, if it becomes widely applied. Change of that magnitude takes time and sustained effort in any setting, including the Corps. Actual application of the tool by the Corps will require concept refinement and case study evaluation to prepare it for guidance manual development. But before moving on to the development stage, questions about policy consistency, scientific validity, and practicality need to be addressed.

The BSI was developed to be consistent with policy guidance, which limits restoration to ecological resources, the variety of which is captured in the concept of biodiversity. Because indicators of value also indicate achievement of project and program objectives, the specification of metric needs required a close reading of objectives to discover essential aspects that are often overlooked by casual readings. As the EQ restoration authority and policy guidance for the Corps is interpreted here, the objective of EQ restoration is to restore for desired ecological outputs (resources) having value that does not contribute to economic development for water resource use. That leaves outputs with nonuse value as the target of ecosystem restoration because nonuse value cannot be acceptably measured in monetary terms by the Corps using the only nonexperimental method available (USACE 2000). The common expression of nonuse value in the objectives of Federal environmental law is associated with heritage maintenance (Cole, in preparation (a)). That reading led to the development of a metric for natural heritage value.

Other outputs with different nonuse value may ultimately be shown to qualify for ecosystem restoration investments (each deserving their own metrics), but review of policy guidance did not reveal what those may be. The heritage value associated with restoring biodiversity to secure status quite comprehensively addresses those indicators of what is acceptable and successful. A metric based on securing biodiversity species by species from human-caused extinction, as the BSI does, represents much of what the Corps has identified as appropriate for its ecosystem restoration mission. Project contributions to biodiversity security also contribute to achievement of the Corps' environmental sustainability goal (USACE 2002), the goals of NEPA and ESA, congressional policy to "maximize sustainable economic development" in Federal water resources planning (Section 2032 of the 2007 Water Resources Development Act), achievement of national and global sustainable development (WCED 1987), and the maintenance of natural capital (Goodland and Daly 1996).

Most of the many metrics now used by the Corps less clearly address the intent of Corps restoration authority, as interpreted here. Being unclear in focus and limited in application, they tend to impede program cost-effectiveness (Cole, in preparation (a)). Increased clarity in the intents of the metric should facilitate Corps application of the BSI, but also introduces new concepts that may not be wholeheartedly welcomed by a culture accustomed to certain planning practices despite shortcomings.

The need for focus and clarity extends beyond the Corps to its stakeholders and collaborators. As a direct indicator of value added, the BSI has the potential to compare more clearly across programs in different organizations as well as across plans and projects within the Corps. That should facilitate recent emphases on more effective collaboration of the Corps with other organizations. The potential role of the Corps in restoring biodiversity to secure status is significant, but falls far short of total need. It needs to collaborate more to become more effective. The anticipated costs of securing biodiversity are high and require close coordination and fiscal collaboration among government and nongovernment organizations to be successful (Groves 2003). Inefficiency is the enemy of national and global objective achievement.

Like any method or tool, additional training may be necessary before the BSI can be used more or less independently in project and program planning. The elements of the BSI concept are conceptually well developed

and should be easy to understand by planning specialists well grounded in the principles of ecology and conservation biology, and informed by basic principles of resource economics pertaining to value measurement. A good analogy is monetary benefits estimation, which is not mastered by taking a 40-hour training class alone. Specialists grounded in economics principles are necessary to do the job well. Similarly, biologists with a good grasp of ecological, conservation planning, and nonmonetary valuation principles should be a fundamental human resource for all EQ restoration planning. This need exists regardless of which benefit metric is used for EQ improvement projects.

Arguably, the most challenging conceptual aspect of the BSI is residual risk estimation. Regardless of how thorough plan formulation is, some residual risk of not adding restoration value as planned is virtually assured in any restoration project setting. Unlike other metrics, the BSI focuses on the sustainability of clearly identified species populations rather than on habitat for ecological resources that are not defined by the metric itself. Risks of failure in restoring viable populations are identified largely through the ecosystem needs of the populations within and outside of the area to be restored. Scientific principles of and methods for landscape, ecosystem, and population restoration are reasonably well developed and improving, but much uncertainty and associated risk remains in their application. That is the primary reason that the probability of success is estimated somewhat subjectively at high, medium, and low levels. But ignoring residual risk because it cannot be precisely estimated ignores a critical aspect of the value added by projects and can be a major source of program cost-ineffectiveness.

One issue of importance for organizational acceptance is the flexibility allowed for setting priorities based largely on different organizational missions and levels of expertise. Policy flexibility is facilitated by including the option to choose different policy weights. Outside social acceptance of the policy weights used by an organization has nothing to do with the metric per se, but with the way organizational mission and policy is perceived. It may make policy sense to weight the populations for recovery based on the estimated effort required to restore a species to a viable status, but there are other important considerations. In collaboration with others, the Corps, for example, may be determined to be best suited to focus its efforts on certain categories of conservation status fitting with its expertise and leave other categories to other organizations.

Whatever policy weights are chosen, the same weights must be used to compare projects and programs. Even if different policy weights are used at project and lower program levels, a uniform policy can be applied at a higher level of program comparison as long as the data used to calibrate the index are passed along with the index scores. In the Corps, for example, the metric used to rank projects for annual budget priority could be calculated based on the policy preference of the program even if weights differ among individual projects. A more efficient approach, however, would be to assure that the same weights are used at projects across the entire program.

Practicality applies primarily to the ease of use for Corps planners. An important consideration is data availability and ease of use. Data for calibrating security status and distinctiveness are widely available and easily accessible in the NatureServe Explorer database. Its data inventory is widely accepted by conservation organizations in and outside of government as the most recent summary of species conservation status in the United States. It is accessible on the internet. Even so, local expertise is a valuable asset. With help from local experts, it can be used to assemble a list of species in the vicinity of a proposed project area and to determine their security status and distinctiveness.

NatureServe Explorer provides data on risks to the extent they are available, but little insight into how to manage them at a project site or how to estimate residual risk. But this difficulty applies to plan formulation for any restoration project regardless of the metric used. Residual risk assessment may be the most difficult aspect of BSI calibration, but both the need to address it and the difficulty of doing so are transparent in the BSI, unlike other metrics now in use. Improved guidance for assessing residual risk needs to be developed, whether or not the BSI is the metric used. A protocol for BSI calibration of the risk term is planned for future development if the BSI concept is accepted by the Corps as worthy of further development for actual application.

One of the least practical aspects of existing metrics is the confusion that often exists over their relationship to project objectives and the value they intend to indicate (which should be proportional to objective achievement) (Brandreth and Skaggs 2002). This confusion exists largely because the link between the benefits metric and the outputs desired for objective achievement is not clear. The BSI clearly indicates heritage value based on

achieving biodiversity security. As long as the data used to calibrate the BSI are passed on with the feasibility study report, as they should be, the desired outputs are impossible to miss and can be independently evaluated.

While the BSI appears to be an improved alternative, a thorough comparison of this metric to other metrics now used by the Corps is needed. The various metrics should be compared based on their scientific merits and ability to reliably indicate relative ecosystem value at program and project levels consistent with Corps policy. The comparison should also consider the predilections of the existing Corps culture as it applies to metric use in restoration planning. Cole (in preparation (b)) has completed an initial analysis of concept consistency with Corps policy, scientific criteria for ecosystem performance indicators, and present Corps practice.

In sum, the BSI is a possible alternative to existing metrics used to indicate benefits from Corps projects and programs. It has the significant advantage of indicating the relative value of projects and programs clearly and directly. The concept of heritage value that BSI measures appears to be comprehensive for all of the indicators of output attributes and project success provided in Corps policy. But the extent to which it can be used in place of all other metrics remains to be resolved. If the concept presented here stands up to evaluation, it requires some further refinement and guidance specification before it is introduced for general application in Corps ecosystem restoration planning.

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